

# THE EFFECT OF MINORITY CARRIER MOBILITY VARIATIONS ON THE PERFORMANCE OF HIGH VOLTAGE SILICON SOLAR CELLS

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## INTRODUCTION

The Lewis Research Center has been engaged in an effort to understand and optimize a multistep diffusion (MSD) processing schedule which has enabled the attainment of high open circuit voltages in 0.1 ohm-centimeter silicon solar cells. The schedule, described elsewhere (ref. 1), consists of a deep primary diffusion, followed by an acid etch of the emitter surface, which is then followed by a shallow secondary diffusion. In the course of our work we have been able to correlate the voltage increases we have observed with the time of primary diffusion. We found that as the primary diffusion time is increased, the voltage rises monotonically (ref. 1).

The working hypothesis we have devised to explain this correlation is based on localized changes in the base minority carrier mobility. The mobility changes are thought to be caused by stress fields emanating from the emitter, which is itself in a state of high diffusion-induced stress. The existence of highly stressed regions in the cell base near the junction can be inferred from the presence of diffusion-induced dislocations in these regions (refs. 2 and 3). Specifically, it is suggested that the stress fields from the highly doped emitter extend beyond the junction into the base and there cause a localized piezoresistive decrease in the minority carrier mobility. It is further suggested that the width of this region of low mobility increases as the time of primary diffusion increases. The observed voltage increases, therefore, are due to the increasing width of a region of low mobility.

The purpose of this paper is twofold. We first will describe some surprising results obtained while trying to model this variable-mobility structure. Second, we will show how the variable-mobility structure was used to explain some unexpected experimental data obtained from high-voltage MSD cells.

## MODELING THE VARIABLE MOBILITY STRUCTURE

Figure 1 shows the calculated variation in the open-circuit voltage with the width of the low-mobility region for the cell described in the figure. As can be seen the voltage rises as the width of the low mobility region

increases. Voltage variations such as these should be expected when changes are made in the mobility since the mobility occupies a prominent position in the expression for the device saturation current.

On the other hand, one would not expected the short-circuit current or the spectral response to be affected by mobility changes. It is known, for example, that for a homogeneous base cell, the current and the spectral response are completely independent of the value of the base minority carrier mobility as long as the rear surface recombination velocity differs from the diffusion velocity by a couple of orders of magnitude. We were surprised, therefore, when we derived the current equations for the case of a cell with an abrupt mobility variation in the base. We found, in contrast to the homogeneous base case, that the current expressions contained the ratio of the mobilities employed in the two base regions. Thus, while the current and the spectral response are independent of the actual values of the mobility, they are functions of the change in mobility from one base region to the other.

Figure 2, for example, shows the variation of the 0.9-micrometer spectral response as a function of the width of the low-mobility region for the cell described in figure 1. The plot is independent of the absolute values of the mobility, depending only on their ratio, which in this case is an arbitrarily chosen 10:1. A parametric study has shown that the current variations increase as the ratio increases for a given region width. Also, as the ratio is increased, the current minimum occurs at lower region widths. Lower diffusion lengths also cause a decrease in the region width for minimum current. As expected, the blue response is not affected by these base mobility changes. The total current shows essentially the same behavior as the red response. It should be noted that the red response (and the total current) are extremely sensitive to mobility variations that occur within a few micrometers of the junction, a region that would be most highly affected by fabrication procedures such as diffusion.

In Summary, it has been found that (1) both the short-circuit current and the spectral response are functions of the mobility ratio, (2) the magnitude of the current and spectral response variations depend on the degree and location of the mobility change, and (3) the short-circuit current and the spectral response are extremely sensitive to mobility changes occurring within a few micrometers of the junction.

#### COMPARISON WITH EXPERIMENT

The present Lewis MSD high-voltage cell is a deep-junction device. Final junction depths of 3 to 4 micrometers are typical. Inherent in such a device is a low blue response and thus a less-than-desired short-circuit current. In an effort to increase the blue response, the junction depth in each of several completed cells was reduced by chemically etching the emitter surface between the grid fingers. The expected improvements are illustrated in figure 3 where the calculated spectral response and short-circuit current are plotted for several values of the junction depth

for a cell with a homogeneous base. As the junction depth is decreased, we would expect a rise in the blue response, no change in the red response, and a rise in the total current.

The measured variations in current and spectral response at various stages in the etching procedure are shown in figure 4. Here, the blue response increases with junction depth reduction as expected, but the red response and the short-circuit current exhibit severe and unexpected decreases. It appears that we have significantly altered the electrical characteristics of the base without touching it directly. While we cannot explain this behavior with a homogeneous base models, we can get some insight into what is happening by invoking the variable base mobility concept.

If, as we have proposed above, long diffusions cause stress fields to be propagated into the base from the highly doped and highly stressed emitter, it then follows that, when we remove highly stressed emitter surface regions, we also allow stress relief to occur in the base; that is, we allow the width of low-mobility region to shrink. If we calculate, then, the variation of the spectral response as the width of the low-mobility region decreases as a result of the surface etching, we obtain the set of curves shown in figure 5. In this figure, an arbitrary mobility ratio of 100:1 was used, and the junction depth (and hence the blue response) was held constant at about 3 micrometers for simplicity. The results are quite similar to what was observed experimentally.

It thus appears that we can explain, qualitatively at least, the unexpected drop in red response with emitter etching by using a model that relates the highly stressed regions in the emitter with regions of lowered minority carrier mobility in the base.

## CONCLUSIONS

The results of this study can be summarized as follows:

1. While the short-circuit current and the spectral response are independent of mobility in an homogeneous base cell, they are functions of the change in mobility in an inhomogeneous base cell.
2. Short-circuit current and spectral response variations depend on the degree and location of the change in mobility.
3. The short-circuit current and the spectral response are extremely sensitive to changes in mobility that occur in a narrow ( $<5 \mu\text{m}$ ) region adjacent to the junction.
4. Unexpected spectral response changes due to emitter etching in MSD cells can be explained using a mobility variation model.

## REFERENCES

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3. Lawrence, J. E.: Diffusion-Induced Stress and Lattice Disorders in Silicon. J. Electrochem. Soc., vol. 113, no. 8, Aug. 1966, pp. 819-824.

# EFFECT OF MOBILITY VARIATION ON OPEN CIRCUIT VOLTAGE

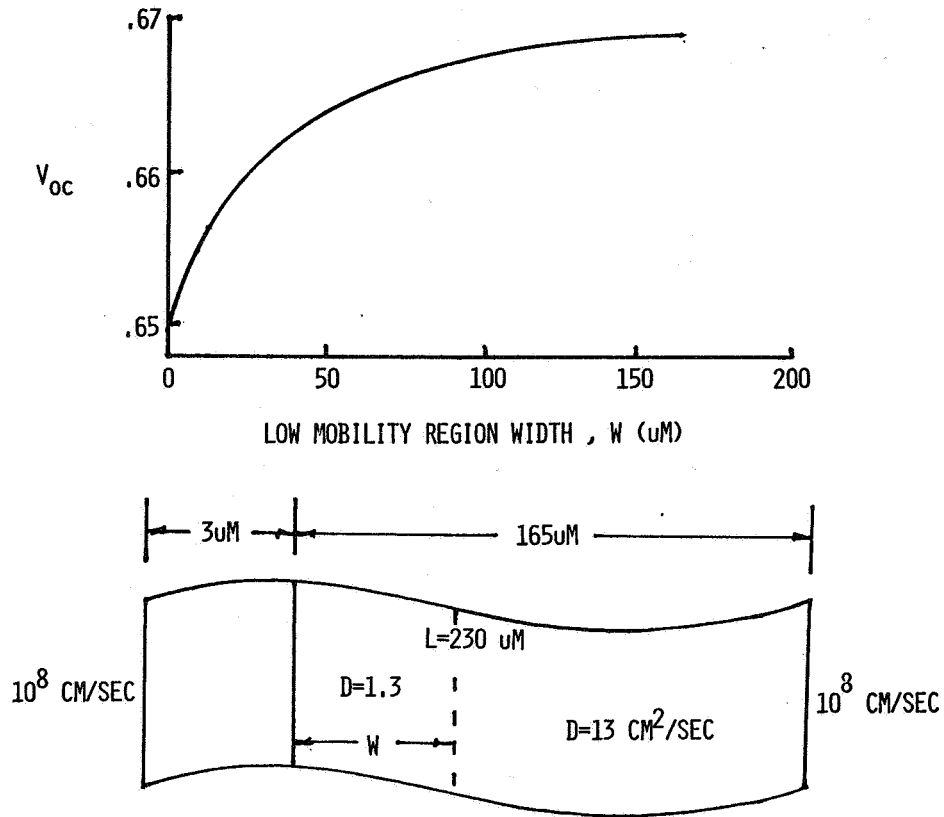


FIGURE 1

# EFFECT OF MOBILITY VARIATION ON RED RESPONSE

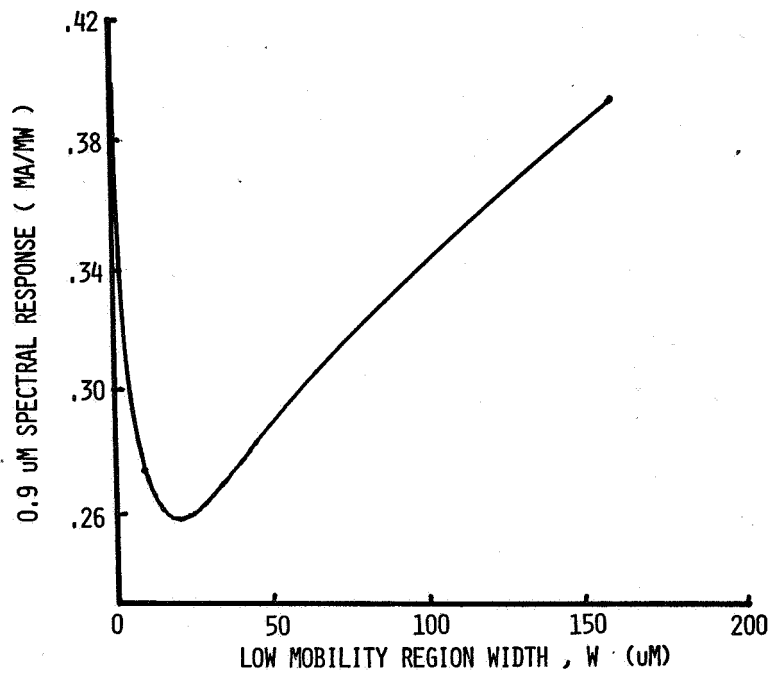


FIGURE 2

# UNIFORM BASE CELL ; EFFECT OF JUNCTION DEPTH VARIATIONS

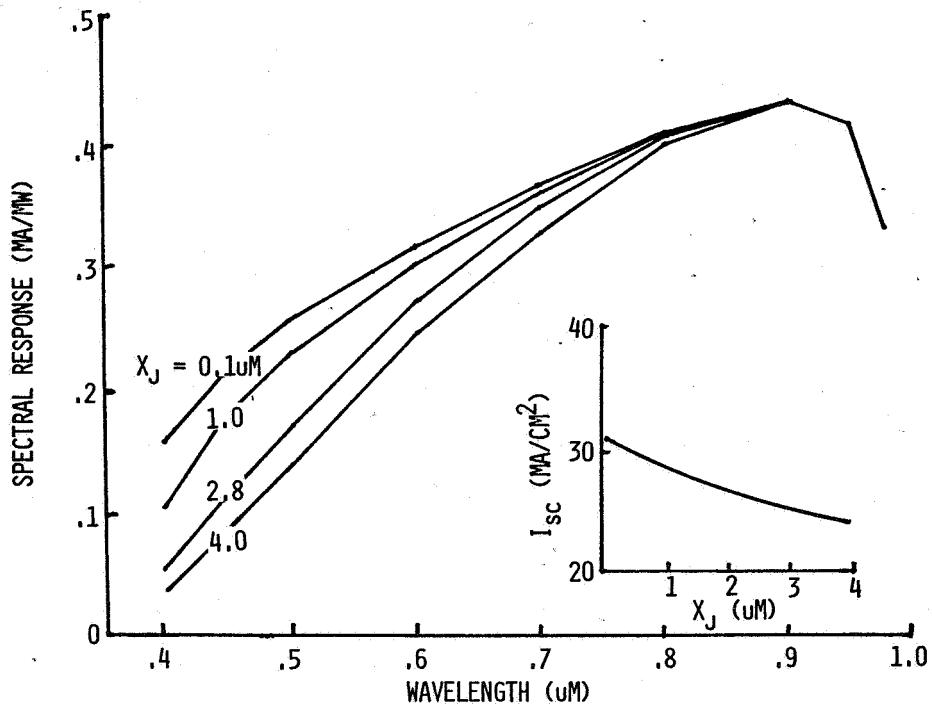


FIGURE 3

# EMITTER THINNING EXPERIMENT

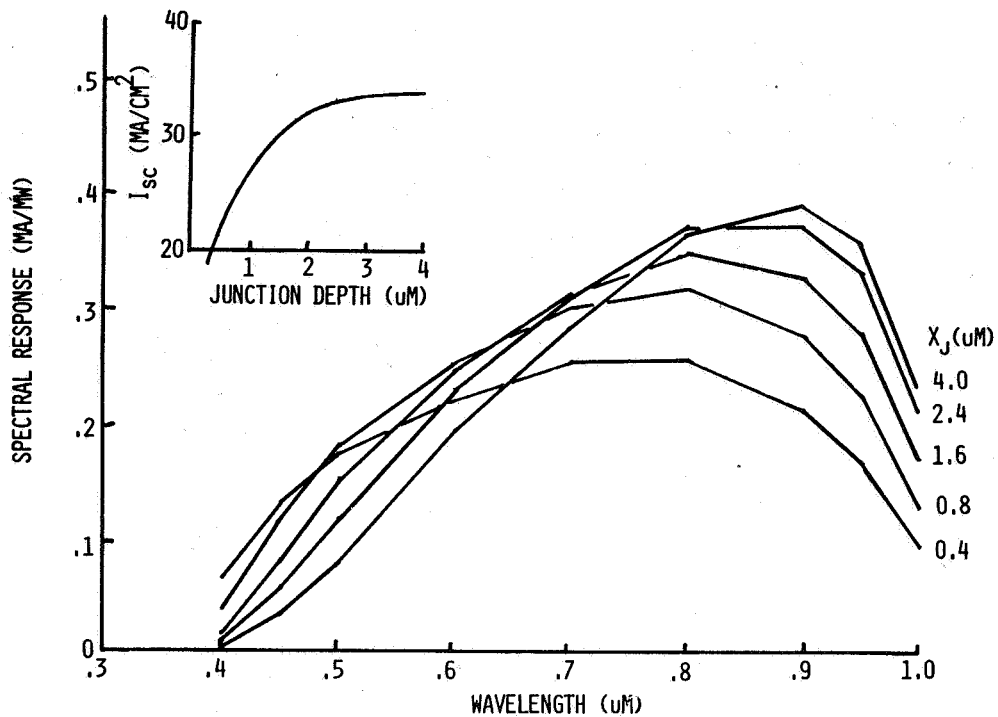


FIGURE 4

## CALCULATED VARIATION OF SPECTRAL RESPONSE WITH LOW MOBILITY REGION WIDTH

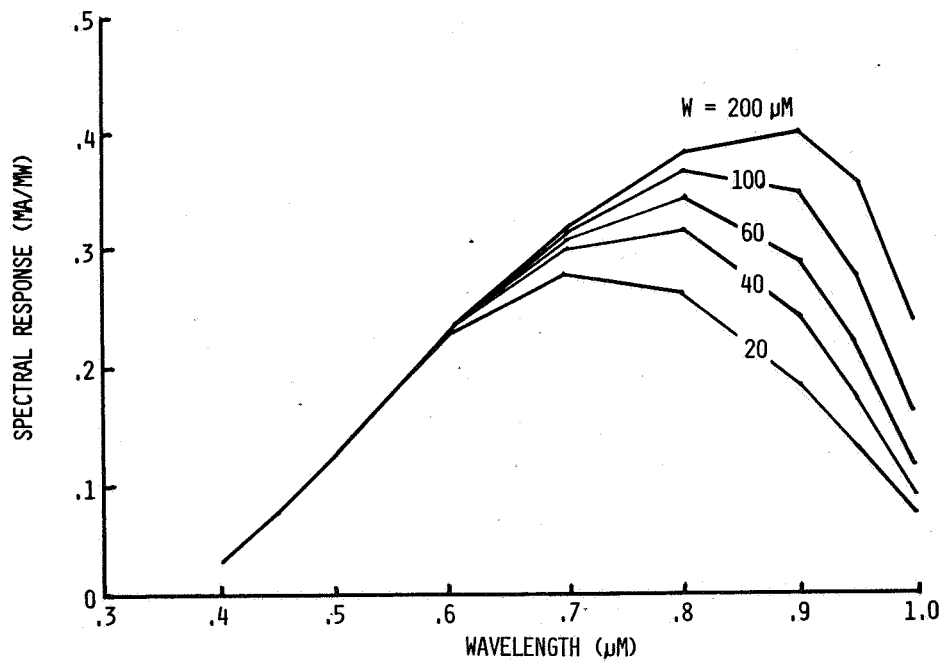


FIGURE 5